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TITLE PION INDUCED DOUBLE-CHARGE EXCHANGE ABOVE THE RESONANCE

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Pion Induced Double-Charge Exchange Above the Resonance

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Abstract

The zero degree excitation function for (π^+, π^-) is calculated for pion energies of 300 to 1400 MeV assuming a sequential mechanism. The cross section around 1225 MeV is 10^4 smaller than at 800 MeV. Experiments at this energy should be ideal for searches for effects due to exchange currents, and other non-conventional mechanisms.

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I Introduction

Pion-induced double-charge-exchange (DCX), (π^+,π^-), has generated a considerable amount of theoretical and experimental work[1],[2] since the pion factories began operation. Despite the considerable work on DCX in the region of the (3,3) resonance, there appears to be greater understanding of the DCX reaction at 50 MeV incident pion energy[3],[4],[5] where the work is much more recent than in the 120 to 300 MeV region. This is in part due to the many possible mechanisms that appear to contribute around the resonance whereas at the lower energy the reaction seems to be dominated by the sequential mechanism - although spin-flip must be taken into account.

The original reason for excitement at the results for lower energies was the observation that, although the single-charge exchange (SCX) zero degree cross section was small, the double-charge-exchange (DCX) zero degree cross section is relatively large. This generated hope that one was observing effects of exotic phenomena such as six-quark bags[6] or exchange currents[7]. Unfortunately, the initial hopes have been frustrated because the sequential DCX process–in which the incident π^+ charge exchanges on a neutron and the resulting π^0 subsequently undergoes a charge exchange on a second neutron, Fig. 1 -has an appreciable cross section. Although the s- and p-wave πN interactions approximately cancel at 50 MeV and conspire to give a small zero degree cross section, there is an appreciable SCX cross section at larger angles via sin-flip. One can thus get an appreciable zero degree DCX cross section by two successive SCX reactions through large angles. The cross section calculated from such a process is roughly of the experimentally observed value and, hence, it is difficult to extract any firm evidence for more exotic effects.

With the recent advent of DCX at LAMPF at energies up to 550 MeV as well as the imminent possibility of DCX at even higher energies at KEK, it is of interest to explore the nature of the interaction at these higher energies. With a shorter de Broglie wave length the pion should in principle be more sensitive to the short range details of the reaction; thus it might be possible to more easily investigate

Figure 1: The sequential mechanism for pion-induced double charge exchange. In this work we assume the intermediate particle is a π^0 although other neutral mesons could be allowed.

two nucleon correlations at these energies. At higher energies the πN cross section becomes very forward peaked. Thus, were there an energy for which the elementary πN SCX amplitudes were small, it would be quite unlikely (but not impossible) for there to be appreciable contributions to DCX through two successive SCX reactions. It has also been frequently pointed out that above the (3,3) resonance, other πN resonances appear, each having unique effects on the spin and isospin properties of the πN interaction. What are the effects such resonances have on predicted DCX cross sections?

In the calculations reported here, we shall confine ourselfs to a discussion of the sequential mechanism - figure 1. This is the simplest - and away from the (3,3) resonance - apparently the most likely mechanism to cause DCX. In this work we consider only the π^0 as the intermediate meson, although other neutral mesons, such as the η, ρ^0 or A_1(??) could be considered. However, recent work by Chiang *et al.*[8] sugests the width of the η is much broader than previously thought[9],[10] and will thus hav little impact on DCX. *Eulogio check!*

II Formalism

As one moves into unfamilar territory, one wishes to employ models that have a minimum number of free parameters, are readily open to interpretation, provide physical insight and - last, but not least - are reasonably reliable. We shall use the Glauber model, which has the additional advantage of being microscopic, yet has been found to provide reliable estimates of cross sections at resonance energies. At the pion energies with which we are dealing, the pion is less strongly absorbed and details of nuclear structure will be important.[1] Our version of the Glauber model[12] allows the explicit use of shell model wave functions. With increasing pion energies, the model should be more accurate as the πN cross section becomes increasingly forward peaked. Finally, the effects of higher partial waves may be explicitly included.

The amplitude for (π^+, π^-) (or, with appropriate interpretation of the wave functions, any hadronic reaction) on a nucleus of A nucleons in the Glauber approach may be written as

$$F(q) = \frac{ik}{2\pi} \int d^2b\, e^{i\vec{q}\cdot\vec{b}} \left\langle \Psi_{fin} | 1 - \prod_j^A (1 - \Gamma_j) | \Psi_{in} \right\rangle \qquad (II-1)$$

where b is the impact parameter, k the incident pion momentum, $\vec{q} = \vec{k} - \vec{k}'$, and Γ is the profile function

$$\Gamma(\vec{b} - \vec{s}) = \frac{1}{2\pi i k} \int d^2q\; h(q)\, e^{-i\vec{q}\cdot(\vec{b}-\vec{s})} \qquad (II-2)$$

in which $\vec{s}$ is the position of the bound nucleon. The profile function may be obtained from the πN amplitude:

$$h(q) = f(q) + i\, g(q)\, \vec{\sigma} \cdot \hat{n} \qquad (II-3)$$

where

$$h(q) = h^{(s)}(q) + \vec{\Theta} \cdot \vec{\tau} h^{(v)}(q)\,. \qquad (II-4)$$

[1] It has been known for a decade[11] the calculated DCX cross sections in the resonance region a very sensitive to details of nuclear structure.

and similarly for f and g. In Eq. (II-4), the superscripts s and v refer to isoscalar and isovector, respectively. The operators θ and τ are isospin operators for the pion and nucleon, respectively. The πN amplitudes $h(q)$ are calculated using the usual partial-wave expansion. The non-spin-flip amplitudes are obtained from

$$f = \sum_l [(l+1)f_{l+} + l\, f_{l-}]\ P_l(cos\theta)$$

and the spin-flip amplitudes are

$$g = \sum_l [f_{l+} - f_{l-}]\ P_l'(cos\theta)\, sin\theta$$

The πN phase shifts and inelasticity parameters used are those of Arndt's 1987 analysis[13]. The πN amplitudes were calculated including patial waves up to an ℓ of 5.

The operator appearing in (II-1) may be expanded as

$$1 - \prod_j (1 - \Gamma_j) = \sum_j \Gamma_j - \sum_{j\neq k} \Gamma_j\Gamma_k + \sum_{j\neq k\neq l} \Gamma_j\Gamma_k\Gamma_l - \ldots \qquad (II-5)$$

Since at least two scatterings are required for DCX, the first term on the right of eq. (II-5) does not contribute. Rather than sum the full series (which is finite), when evaluating this operator for inelastic scattering we make use of a simple property of determinants to evaluate the expectation value. Since the operator in Eq. (II-1) is a product of A one-body operators, if the shell model wave functions are determinants, then the evaluation of Eq. (II-1) reduces to the evaluation of an $A \times A$ determinant. The calculation of Eq. II-1 reduces to the evaluation of a sum of $A \times A$ determinants; antisymmetry is thus explicitly included. By using the Glasgow shell model code, the wave functions are naturally expressed in a sum of Slater determinants, and hence, antisymmetry is explicitly included. The antisymmetric nuclear wave functions for ^{14}C and ^{14}O were obtained using Cohen-Kurath matrix elements [14].

However, there is a complication that arises when charge-exchange is allowed to occur. Clearly, the intermediate π^0 can't scatter off a nucleon until it has been created through an earlier charge exchange; a similar statement applies to the π^-. Thus, there must be a time ordering implied. In the small angle approximation, this is equivalent to:

$$\prod_{j=1}^{A} \rightarrow \sum_{permutations} (1-\Gamma_1)(1-\Gamma_2)\cdots(1-\Gamma_A)\theta(z_2-z_1)\cdots\theta(z_A-z_{A-1}). \quad (II-6)$$

One can easily demonstate that if the Γ_j commute, one needn't worry about the time ordering and one can simply use eq. (II-1). In general one does not have

$$[\Gamma_i, .\Gamma_j] = 0, \ \ i \neq j$$

because the pion isospin operator $\vec{\Theta}$ does not commute with itself. However, there is no difficulty in the leading order term since both $\vec{\Theta}$ operators are necessarily lowering operators which do commute. [Obviously, since the time ordering was introduced simply to ensure a π^0 is created before the π^-, difficulties will only arise in higher order terms.] Since the isoscaler parts of the operator mutually commute, one can ignore time ordering if one retains the isovector only for the second order term. In this approximation one has:

$$F(q) = -\frac{ik}{\pi}\int d^2b\, e^{i\vec{q}\cdot\vec{b}} \left\langle \Psi_{fin} \right| \sum_{i\neq j} \Gamma_i^{(v)}\tau_i^+ \Gamma_j^{(v)}\tau_j^+ \prod_{k\neq i,j}\left(1-\Gamma_k^{(s)}\right)\left|\Psi_{in}\right\rangle \quad (II-7)$$

It should be remarked that the lack of commutativity is independent of whether spin-flip is included.

III Results

Assuming the 1987 phase shift analysis of Arndt, [13] around 1225 MeV isovector d and f amplitudes cancel the g and h amplitudes. The resulting $^{14}C(\pi^+,\pi^0)^{14}N$ cross section is calculated to be 1 mb compared with 4 mb at 800 MeV and a measured valued of approximately 4 mb at 500 MeV. (The model used for this calculation is that described in Refs. [11] and [12] with a generalization to include more partial waves.)

Figure 2: The calculated zero degree cross section for single-charge exchange ${}^{14}C(\pi^+,\pi^0){}^{14}N$. Cohen-Kurath wavefunctions and all partial waves up to and including l = 5 were used.

The calculated SCX angular distribution for an incident pion energy of 1.2 GeV is shown in Fig.2. The reaction is forward peaked and, as discussed above, this makes it unlikely that two large angle πN reactions will give an appreciable contribution to the zero degree DCX cross section.

is this relevant?

The zero degree excitation function for ${}^{14}C(\pi^+,\pi^-){}^{14}O$ is shown in Fig. 3. One observes a very deep minimum around 1225 MeV. The calculated cross section of 10^{-1} nb/sr is 10^5 times smaller than that at 600 MeV. This is much smaller than experimentally detectable.

I wish to include the effects of spin-flip, but not Gamow-Teller.

The Glauber model should be quite accurate at these energies. Hence, the experimental observation of DCX around this energy would be of great interest and would imply contributions from processes other than the conventional, successive mechanism. The double Δ mechanism is not appropriate for this region. Among the other possible contributors are six-quark bags,meson-exchange currents, successive SCX reactions proceeding through a ρ, spin-flip and many others. If the six-quark bag mechanism were roughly independent of energy, then the approximately 4 nb/sr

Figure 3: The calculated zero degree cross section for $^{14}C(\pi^+,\pi^-)^{14}O$ from 300 to 1200 MeV pion kinetic energy. Cohen-Kurath wavefunctions and all partial waves up to and including $\ell = 5$ were used.

cross section calculated assuming a six-quark bag for a pion incident energy of 50 MeV would be - for an incident energy of 1200 MeV - four orders of magnitude larger than that due to the successive mechanism.

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